DESIGN AND ANALYSIS OF TWO LAB-GRADE PROTOTYPE INSTRUMENTS FOR DIRECT-SEQUENCE SPREAD-SPECTRUM ULTRASONIC EVALUATION (DSSSUE)

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INTRODUCTION

Direct-Sequence Spread-Spectrum Ultrasonic Evaluation (DSSSUE) is a new technique for the nondestructive testing of materials. It applies the correlation properties of pseudo-random noise to ultrasonic NDE using spread-spectrum technology. The theoretical analysis of this technique and various system design options for its implementation were studied in [1] and [2] respectively. Based on this study, two prototype lab-grade instruments have been built. These instruments are functionally equivalent but have been designed with two different implementation approaches. One instrument implements the technique making maximum use of digital signal processing and software. The second instrument implements most of the signal processing functions in hardware. This paper describes the implementation details of the two instruments, discusses various problems encountered and their solutions along with the practical limitations. It also presents some early work on the signature analysis techniques.

SYSTEM OVERVIEW

A basic system block diagram is shown in Figure 1. The system fundamentally consists of a spread-spectrum transmitter and a spread-spectrum correlation receiver. The transmitter, in addition to generating a bandpass spread-spectrum signal, $s(t)$, also produces a delayed replica of the spreading code, $c(t-\tau)$, which is required for the signal despreading in the correlation receiver. Various components of both the transmitter and the receiver are controlled through a host computer. Also, the computer takes the raw correlation data and processes it to generate the so-called "ultrasonic correlation signature." The final task of signature analysis and signature interpretation is also performed in the computer.

MAXIMAL SOFTWARE APPROACH

The Maximal Software Approach (MSA) implements the DSSSUE process while placing as much of the functionality in software as possible. The entire process of generation of DSSS signals, correlation and postprocessing is carried out in software, making the MSA the most flexible approach to DSSSUE possible. Figure 2 illustrates the implementation of the MSA system. A personal computer generates a maximal-length (ML) pseudorandom binary code. This code is modulated, in software, on a sinusoidal carrier sequence. The resulting sequence is then downloaded to the arbitrary function generator (LeCroy 9101). The AFG, acting as the DSSS transmitter, converts the sequence into an analog waveform which is amplified and input

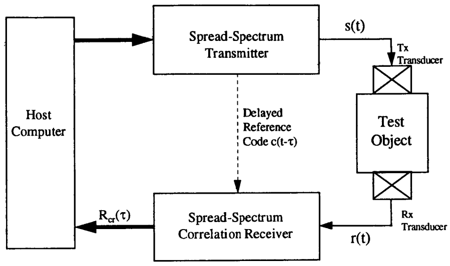

Figure 1. Basic system block diagram.

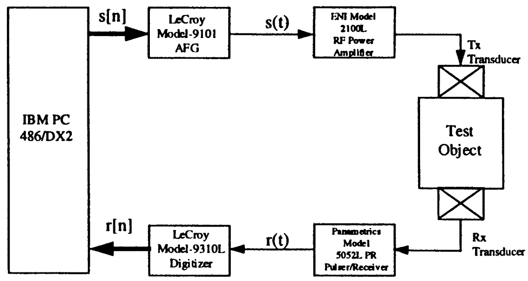

Figure 2. MSA implementation of DSSSUE system.

to the transmitting transducer. In the current implementation the clocking frequency reference for the arbitrary function generator may be selected from one of three sources: 1) the master digitization clock of the oscilloscope, 2) a frequency synthesizer (HP3325A), or 3) an external source such as a crystal oscillator. The transmitted signal from the AFG, $s(t)$, after amplification and impedance matching, if necessary, excites a piezoelectric transducer, acoustically transmitting the DSSS signal through the object under test.

A second transducer receives the response of the test object to the DSSS signal $r(t) = h(t) * s(t)$ where $h(t)$ represents the impulse response of the acoustic channel. The received signal is digitized by a digital oscilloscope (LeCroy 9310L). The controlling computer then uploads the received signal sequence from the oscilloscope and correlates it with a reference signal

$$R_{\tilde{s}r}[k] = h_c[n] * r[n] = \sum_{n=0}^{N-1} \tilde{s}[n+k]\, r[n] \tag{1}$$

where $h_c[n]$ represents the transfer function of a correlation filter. This process records a correlation signature function containing the aggregate acoustic information available from the object under test. However, the world is not ideal. The same physical and technical limitations that limit the sensitivity of traditional NDE techniques also affect the DSSSUE technique. The DSSSUE technique, due to the nature of its signalling structure, is capable of largely overcoming these limitations. The following sections describe the implementation problems faced by the DSSSUE team and the solutions found to date.

Noise and Interference -- There are three principal sources of noise affecting the MSA instrument. First, thermal noise, generated by random motion of charge carriers in resistive material, is uncorrelated with both the DSSS signal and the impulse response of the object under test. Second is quantization noise, generated by the "rounding off" of the received signal in the process of digitization. This also is uncorrelated with the DSSS signal and the impulse response. Third, electromagnetic interference (EMI), generated either by conduction of interfering signals through power supply lines or other electrical connections or by radiation from electrical equipment or natural phenomena, may be of more concern. While the majority of EMI will be uncorrelated, potential sources of EMI include the DSSSUE system equipment itself resulting in interfering signals which may be correlated. Suppression of the correlated EMI signals (and the uncorrelated EMI signals) is accomplished by traditional means. That is, by installation of shielding and grounding, and by insertion of filters to suppress out of band interference. Suppression of the uncorrelated noise and interference signals is accomplished by the correlation process itself. We may arbitrarily choose the level of noise suppression by choosing the system parameters in the equation for the dynamic range of the MSA implementation,

$$10 \log_{10}\left(\tfrac{1}{2}\, 2^q \sqrt{s\,(2^m - 1)}\right) - 6 \text{ dB} \tag{2}$$

where q is the number of quantization levels in the digitizer, s is the number of samples per chip of the spreading code, and m is the order of the spreading code. The 6 dB represents an